THE EFFECT OF RED ROCK RESERVOIR ON THE PLANKTONIC COMMUNITY OF THE DES MOINES RIVER

An abstract of a Thesis by
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The problem. The objective of this study was to determine the effect of Red Rock Reservoir on the planktonic community of the Des Moines River.

Procedure. This was accomplished by (1) measuring primary productivity of the phytoplankton in terms of C^{14}-uptake using standard lake methods in conjunction with a newly designed sample-holding apparatus to overcome most of the problems attributed to water currents, and (2) ascertaining the fate of phytoplankton passing through Red Rock Reservoir.

Findings. Primary productivity above Red Rock Reservoir was significantly higher than below Red Rock Reservoir. The values recorded for water temperature, available light, essential nutrients and water velocity showed no correlation to differences in primary production. The greatest correlation was found between primary production and the total number of planktonic organisms per milliliter.

Conclusion. Primary production by phytoplankton below Red Rock dam was significantly lower than above Red Rock Reservoir. This difference was apparently due to lower population levels below the dam as a result of cell destruction in passage through Red Rock Reservoir.

Recommendations. It is recommended that a similar study be conducted after Saylorville Reservoir has been impounded to assess its impact on primary production.

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A Thesis

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The School of Graduate Studies

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by

Raymond C. Sherman

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INTRODUCTION

The ecological impact of reservoirs on downstream biota has been noted by several authors. Only a limited number, however, have dealt with the changes occurring in primary production. Wright (1967) found that deep withdrawal from reservoirs tended to make impoundments act in the reverse of natural lakes, i.e., nutrients that accumulated in the deep water of reservoirs during summer stratification would be carried out in the discharge. As an end result Wright theorized that primary productivity below a dam should be increased. With this in mind, it was hypothesized that primary productivity should be greater downstream from Red Rock Reservoir than above the reservoir.

The object of this study was to determine the effect of Red Rock Reservoir on the plankton of the downstream river by (1) measuring primary productivity of the phytoplankton in terms of C^{14}-uptake using standard lake methods in conjunction with a newly designed sample-holding apparatus, and (2) ascertaining the fate of phytoplankton passing into and through Red Rock Reservoir.

Rief (1939) and Chandler (1937) studied the effects of receiving stream conditions on lake plankton. Both demonstrated a surprisingly rapid decrease in net plankton downstream from lakes. Chandler theorized that plankton tended to accumulate on exposed surfaces of submerged debris and other objects. Based on this theory, Chandler felt that

aquatic vegetation filtered out phytoplankton. He reported that heavy vegetation in a receiving stream reduced net plankton by 70% in a distance of 20 meters.

Neel (1963) studied the reservoirs on the Missouri River and made the following observations: 1) as the volume of discharge water increased, the number of plankton below the dam decreased and vice versa, 2) lake plankton usually predominated in the stream below if the discharge rate was only a few 1000 cfs., 3) in shallow situations below the dam, planktonic organisms were often replaced by benthic algae, 4) muddy underflows within impoundments were shown to maintain turbid discharges for extended time periods, and 5) reservoirs usually delay the rise and fall of temperatures in the spring and fall within the tailwater.

Benson and Cowell (1967), Damann (1951), and Neel et al. (1963) found in studies of plankton density in Missouri River reservoirs that the greatest limiting factor to diatoms was turbidity. Hudson and Cowell (1967) demonstrated that as the turbidity increased, phytoplankton populations decreased. Williams (1964) showed that when a drainage area was frozen (thus reducing the amount of turbidity in drainage) the phytoplankton populations increased.

There are currently three basic approaches to productivity measurements within rivers: 1) total productivity, 2) phytoplankton productivity using correction factors, and 3) phytoplankton productivity using standard lake methods.

Each method and its limitation have been reviewed by several authors.

Odum (1956) felt that any productivity measurements taken within a river with no turbulent flow could be questioned on the grounds that production is a function of current. Odum measured total river production by constructing daily oxygen curves for a segment of flowing water to calculate rates of production, respiration and diffusion. From these values he calculated daily production. This method, however, is useful in measuring only total production of the river community and does not differentiate between periphyton and phytoplankton productivity.

Kevern and Ball (1965) used Odum's method to study the effects of changes in temperature, photoperiod, light intensity and current on primary productivity within an artificial stream. A 10°C increase in temperature resulted in doubling of the photosynthetic and respiration rate. No significant differences in production were recorded with differing photoperiods as long as the total time of illumination was the same. One percent of full daylight intensity gave a greater production (5,548 cal/m^2/day) than a lower light intensity (4,151 cal/m^2/day). The effect of slightly increasing current velocity (from 0.5 cm/sec. to 3.4 cm/sec) resulted in an increased oxygen production. Respiration rates between these two sets of current conditions were equal. Kevern and Ball concluded that the more efficient

transfer of radiant energy in the faster stream was due to more efficient nutrient uptake. Whitford (1960) had earlier speculated that an increase in current produced a steeper diffusion gradient, thus facilitating a better exchange of materials between the cells and their environment.

Mann et al. (1972) used standard lake methods (stationary positioning of light and dark bottles containing a water sample) to measure primary production. Five depth strata (0-30 cm, 30-90 cm, 90-150 cm, 150-210 cm, and 210-lower cm) were chosen for sample incubation. Oxygen measurements were made after incubation. In a diversion from the standard lake approach a correction factor of 1.38±0.23 was used to account for the difference in productivity between mechanically rotated bottles (in the laboratory) representing the more natural situation and stationary bottles (in the field). This factor was determined by laboratory tests which were performed to correct for errors in production measurement caused by the lack of directional current within field samples. This is not a major problem in lake studies as water movements within lakes are usually neither massive nor directional. Within a river system, however, these water movements help to keep materials in suspension and also increase the photosynthetic rate by maintaining steep diffusion gradients of nutrients and wastes around planktonic organisms.

The method used by Mann et al. (1972) assumes a

uniform flow throughout the incubation period and also equates conditions between stations; because of this, the validity of any results determined using this method are questionable. Primary productivity due to periphyton was considered minimal because of the depth and turbidity of the river. However, in more shallow and/or less turbid waters periphyton would add appreciably to total production.

Kowalczewski and Lack (1971) using the method described by Mann et al. (1972), measured production (O_2) rates in the River Thames. The value derived using this method was 3.42g O_2/m^2/day (rotation corrected). Hammer (1965), in a study on the Rio Negro, determined values ranging from 0.21 to 0.35g O_2/m^2/day; and Pyrina (1959) determined production values within the Volga and its reservoirs ranging from 0.11 to 1.04g O_2/m^2/day (both without rotation correction).

Traditionally, primary productivity measurements in terms of C^{14}-uptake have been measured in lakes using the method outlined by Steemann-Nielsen (1952) and modified by Vollenweider (1969). In order to measure primary productivity within a river using this conventional method some changes in design would have to be developed to overcome the problems attributable to the effects of current.

In Steemann-Nielsen's (1952) ocean method, water samples (in pairs of one light and one dark bottle) containing a C^{14} source (bicarbonate) were incubated for four hours at the various depths from which the samples were taken. At

the end of the four hour period, aliquots of the samples were filtered through a 0.5 micron membrane filter which was then placed in a desiccator for drying. The amount of C^{14} fixed was determined with a Geiger counter. Since the amounts of C^{14} added, C^{14} fixed, and the total amount of C^{12} within the sample were known, total carbon assimilated was determined assuming that C^{12} and C^{14} were assimilated at a rate proportional to availability.

Steemann-Nielsen's method has been studied, evaluated and employed rather extensively. Qasim et al. (1972) identified some problems related to its use in the measurement of primary productivity. They noted that the size of the bottles used for holding the samples during illumination had no marked effect on the rate of photosynthesis. However, as the amount of inert material within the sample increased, light attenuation within the bottles and self-absorption of beta emmissions on the filters increased. They also showed that large bacterial loads (up to 10^5 cells/ml) were responsible for increased carbon uptake in both light and dark bottles. Bacterial loads larger than 10^5 cells/ml led to a decrease in net assimilation.

Wallen and Geen (1968) also evaluated Steemann-Nielsen's method and determined that desiccation of the samples on filters led to losses of radioactive-labeled carbon (C^{14}). These losses sometimes amounted to as much as 50%. Wallen and Geen, therefore, recommended that

samples be placed directly in scintillation fluid and counted immediately. Lind and Campbell (1969) criticized this recommendation on the grounds that the scintillation fluid which was used lacked water solubility. If a scintillation fluid with greater water solubility could be found, Wallen and Geen's suggestion should be followed. Lind and Campbell also felt that Wallen and Geen's method would not correct for an increased concentration of cells. It was shown by Lind and Campbell that with increased cell concentrations the count efficiency dropped. If the number of organisms on a filter were doubled from 220,000 cells/ml to 440,000 cells/ml, the counting efficiency would be reduced by three percent.

Wetzel (1965) advocated an additional treatment of the filtered sample. He felt that fuming with HCl removed any C^{14} which was not fixed by the cells. Wetzel showed, however, that there was some loss of radioactivity as a result of this treatment, and that this loss was not constant but seemed to vary among lakes, among seasons and between illuminated and dark bottles.

McAllister (1961) in a counter position to Wetzel, noted a 30% loss in activity of samples exposed to isotonic NaCl. He also noted losses due to several other treatments. The conclusion of his study was that smaller errors existed when there was no correction for contamination by C^{14}. McAllister's suggestion was to subtract the amount of carbon

assimilated in the dark bottles from the light.

The depth of light penetration in relation to stream depth determines whether the major amount of carbon is assimilated by periphyton or phytoplankton. If the river is deep and turbid, obviously little carbon will be assimilated by periphyton. Rosmarin (1975) compared primary production (C^{14}) per unit biomass between periphyton and phytoplankton in the Ottawa River using standard lake methods. Conditions for assimilation were equal between samples of periphyton and phytoplankton including light availability. On a C^{14} per unit biomass basis, phytoplankton had a higher rate of photosynthesis than did periphyton. He concluded that river phytoplankton (primarily derived from lentic habitats) were the major primary producers.

Gudmundson (1969) in a phytoplankton study on the Des Moines River noted that diatoms constituted a majority of the total cell count and sometimes became as high as 90% of the total. The total number of organisms per milliliter varied from 3,364 in January to 281,074 in May. In addition, she also plotted dissolved oxygen levels against the number of organisms per milliliter and determined that no significant correlation existed. Therefore, dissolved oxygen level was not used as an indicator of phytoplankton density.

Drum (1964) identified 274 diatom taxa within the

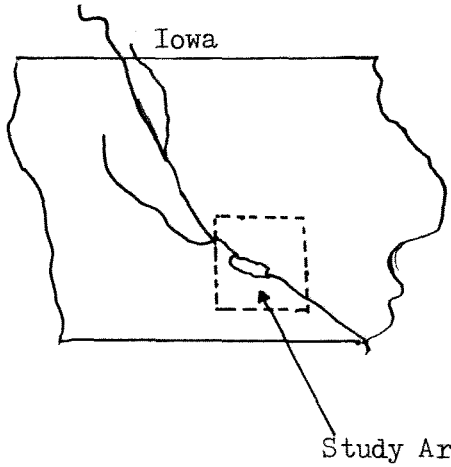
entire length of the Des Moines River prior to the construction of Red Rock Reservoir. Two hundred and nineteen of the diatoms identified were motile pennate forms. Drum observed that heavy or prolonged rains increased the silt load of the river and hence removed most of the diatoms. Replenishment of the diatom population was facilitated by inocula from lakes, ponds, small impounds, permanent springs, seeps, and pools.

MATERIALS AND METHODS

Description of the Study Area

The Des Moines River is a western tributary of the Mississippi River flowing 861 kilometers from southwestern Minnesota through central Iowa to 3.2 kilometers south of Keokuk where it joins the Mississippi River. Over 40,922 square kilometers, mostly agricultural, are drained. Red Rock Reservoir, which is 230 kilometers upstream from the junction of the Mississippi River, is primarily operated for downstream flood control but is also used for low flow augmentation.

Figure 1 shows the relative position of Red Rock Reservoir and the sampling stations within the study area. Table 1 identifies the location and description of these stations.



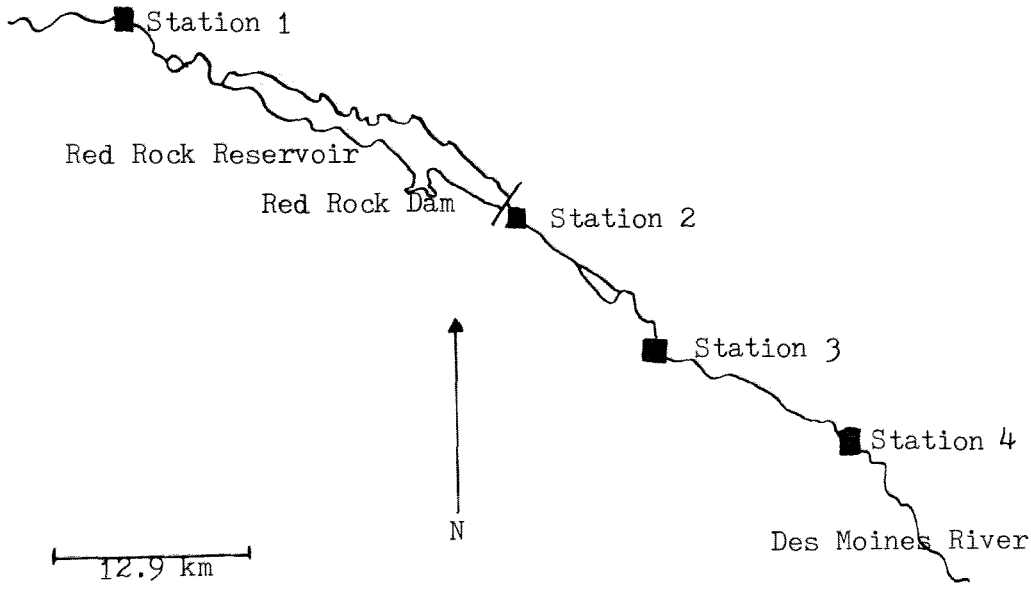


Figure 1. Map of the study area showing Red Rock Reservoir, Red Rock Dam and four sampling stations.

Table 1. Location and description of sampling stations

Station	Location	Description
1	274.7 km* (170.6 mi)	Approximately 10.5 km north of Pleasantville and 44.7 km upstream from Red Rock Dam
2	229.6 km (142.6 mi)	0.4 km below Red Rock Dam
3	210.7 km (130.9 mi)	0.4 km below bridge on State Highway 92, near Tracy
4	197.5 km (122.7 mi)	30.5 meters below bridge on State Highway 309

*Distance above junction with Mississippi River.

Field Procedures

The prerequisite for collection and incubation of samples was clear skies. One station was sampled each clear day. Thus, four clear days were required to sample each station once (one data set).

Sixteen (eight light and eight dark) 300 ml BOD bottles were filled from a water sample collected in a plastic bucket. The stopper was removed from each bottle and one milliliter of water was withdrawn and discarded.

An ampoule containing one milliliter of $NaHC^{14}O_3$ in sterile water was opened and the contents were transferred to the BOD bottle replacing the milliliter removed. (The C^{14} activity was five microcuries per ampoule or 1.11×10^7 disintegrations per minute according to the manufacturer's

specifications). Each BOD bottle was then capped and a balloon was placed over the cap and neck to insure that the caps would remain in place. Finally, the BOD bottles were attached to the sample holder designed specifically for this project and placed back into the river for a four-hour incubation period.

The sample holder was designed to hold 16 BOD bottles on a rim 40.6 centimeters in diameter. Hose clamps which had been welded to the rim were used to secure the bottles. The rim was connected directly to a main drive shaft by four struts. Two sealed pillow block bearings facilitated free movement of the shaft. By attachment of an automobile fan to the end of the shaft, the power required to rotate the bottles was derived from the water flow. The amount of agitation within the BOD bottles, therefore, increased with increasing current velocity. Since comparable data were desired, the sample-holder construction, loading (number of bottles), and operation (position within the stream) were kept constant. For example, if the area of the fan exposed to the current had been decreased, the agitation within the bottles would be decreased and the nutrient gradients would not be as steep; if the load were decreased (symmetrically) then the amount of agitation within the bottles would increase; if the sample holder were placed in deeper or more shallow water it would effectively increase or decrease, respectively, the amount of surface area of the fan exposed

to the current. Thus, all comparable data was to be determined under similar experimental conditions. Figure 2 shows the BOD bottles attached to the sample holder. Figure 3 shows the sample holder in position in the river.

During the incubation period, water temperature, current velocity, light penetration (Secchi disc), and total alkalinity were determined. Water temperature was measured at the position within the stream flow where the sample holder and BOD bottles were placed. Current velocity was also measured at that position using a Gurley-Teledyne current meter. Light penetration was measured using a Secchi disc which was attached to a steel rod rather than a chain so that deflection caused by the current would not occur. Total alkalinity was determined using a method outlined in A.P.H.A. (1971). A 100 ml water sample was taken from the composite sample and titrated to pH 4.5 using 0.02 N sulfuric acid. Since the initial pH of the river water was never greater than pH 7.8, the total alkalinity was bicarbonate alkalinity (methyl orange alkalinity). All of the preceding procedures were performed twice and the average result was recorded. A one-liter subsample of the composite sample was returned to the laboratory for a total phytoplankton count and group identification.

Following the four hour incubation period, the BOD bottles were removed from the sample holder, placed in a dark ice bath and transported to the laboratory.

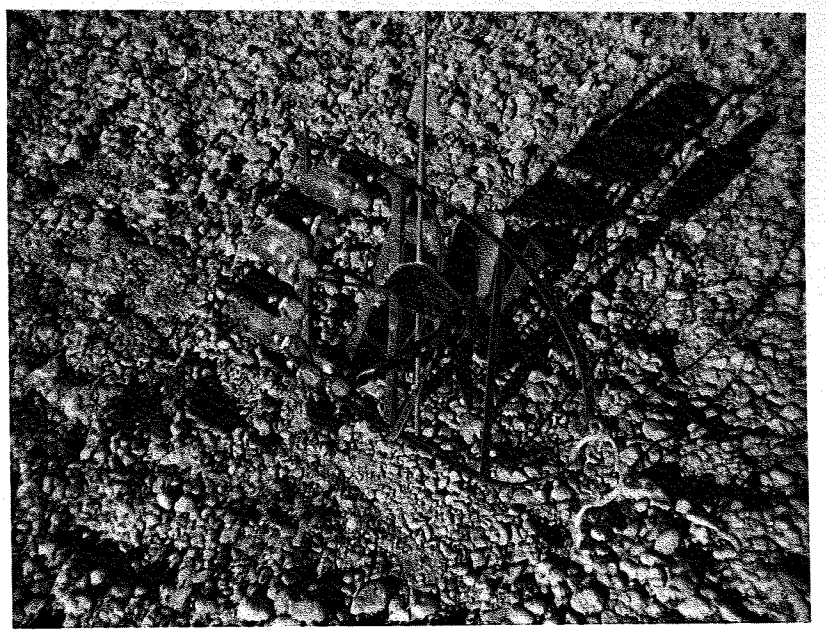


Figure 2. Sample holder loaded with BOD bottles.

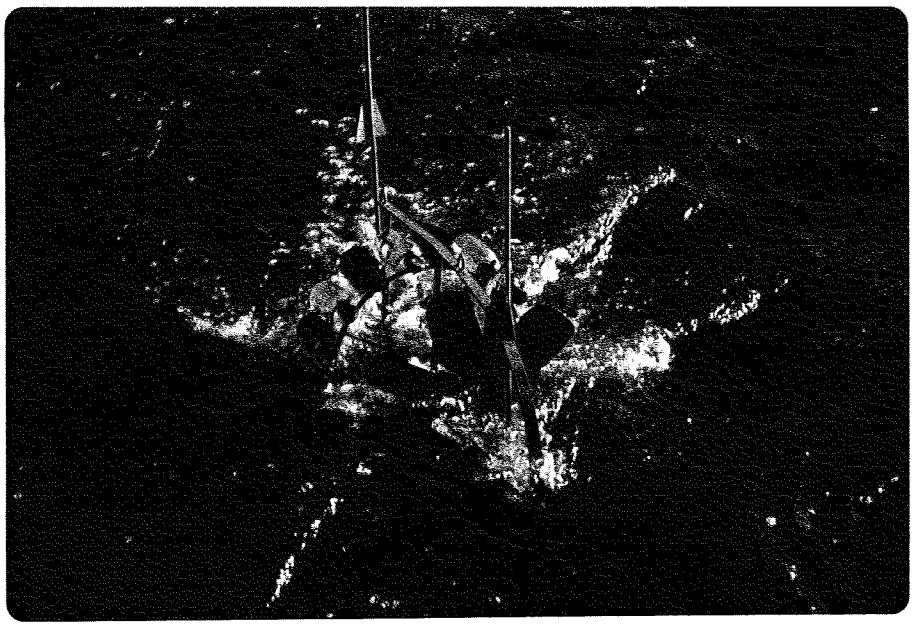


Figure 3. Sample holder positioned in stream flow.

Laboratory Procedures

A 4 ml aliquot from each BOD bottle was added to 15 ml of distilled water and filtered through a 0.45 micrometer membrane filter. (The vacuum applied never exceeded 0.5 atm). Each filter was then transferred to a scintillation vial containing 15 ml of scintillation fluid (Aquasol, New England Nuclear). Counting of the 16 scintillation vials (8 vials containing light bottle samples and 8 from dark bottles) was performed on a Beckman L.S. 100 soft-beta spectrophotometer. The wide channel iso-set for C^{14} was used as well as the external standard iso-set. The print-out from the spectrophotometer showed the number of scintillation counts per minute (a measure of total C^{14} assimilated) and the external standard ratio (a measure of the concentration of quenching agents).

A series of scintillation vials (Picker Quench Standards for C^{14}) were counted with a known C^{14} disintegration per minute (dpm) rate and varying amounts of quenching agent. A quench calibration curve was constructed by plotting the various external standard ratios against the counting efficiencies (Figure 4). This curve was used to obtain counting efficiencies for the field data by inserting the external standard ratio obtained for each vial. Using the counting efficiency, the counts per minute (cpm) recorded by the scintillation counter were converted to disintegrations per minute.

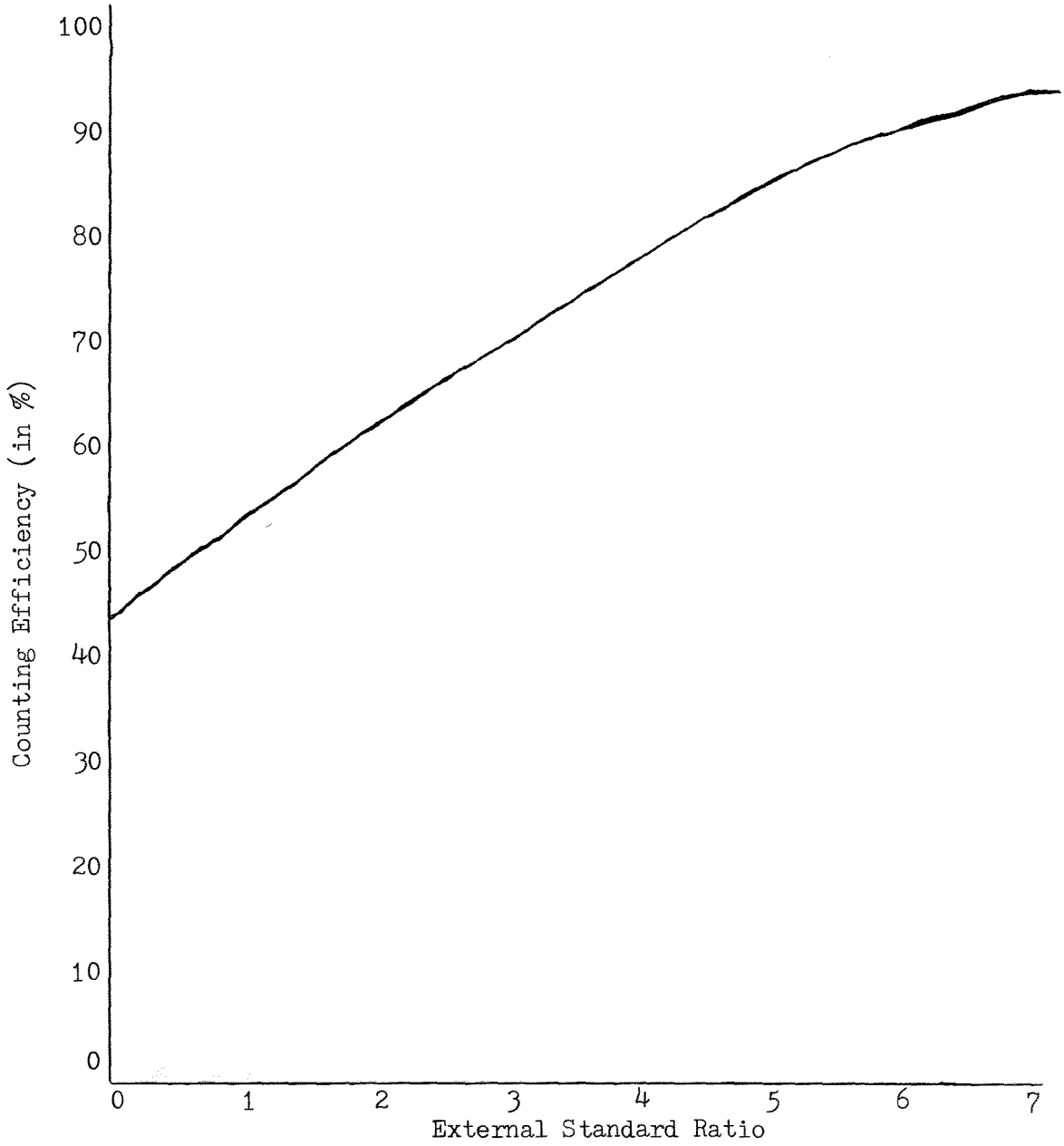


Figure 4. Counting efficiency versus the external standard ratio.

Total carbon assimilated was calculated using the following formula (Vollenweider, 1969):

1) $$C_{assim.} = C_{avail} \times \frac{C^{14}_{assim}}{C^{14}_{avail}} \times K_1 \times K_2$$

C_{assim} = Total carbon assimilated in $mg/m^3/hr$

C_{avail} = Total carbon available (mg/l)
= (Total alkalinity-phenolphthalein alkalinity) x 12 mg/meq
(meq/l) (meq/l)

C^{14}_{assim} = C^{14} assimilated in dpm/hr (of incubation)

C^{14}_{avail} = C^{14} available = 5 microcuries/300 ml or 1.11×10^7 dpm/300 ml or 1.48×10^5 dpm/4 ml

K_1 = correction factor (ie. 80 min incubation instead of 240 min = 3)

K_2 = correction factor (ie. unit changes mg/l to mg/m^3 = 1000)

Identification of the phytoplankton was facilitated by using a key constructed by Prescott (1970). The phytoplankton were counted using a Sedgewick-Rafter counting slide.

RESULTS

All data have been divided into two sets. Set 1 contains the data from the first sampling at each station. Each primary production measurement was based on eight replications (eight light and eight dark bottles). Set 2

contains the data from the second sampling at each station with production measurements based on four replications (except for station 1, which is based on three replications). The data was divided for two reasons. Most importantly, the control station (Station 1) was expected to vary drastically in the total number of organisms per milliliter based on Gudmundson's (1969) data. The time interval required for this increase in phytoplankton numbers was comparable to the time interval between the two samplings at station 1. Also, since the load on the sample holder was different between sets it was felt that the results might not be comparable.

Table 2 contains the measurements and calculated values for data set 1. Table 3 contains the same parameters for data set 2. All of the raw data for the productivity determinations and calculations for both sets can be found in the appendix.

Table 4 contains water quality information measured in the Des Moines River and Red Rock Reservoir during the study period (Baumann, et al., 1975).

Table 2. Parameters for Data Set 1.

Description / Station	1	2	3	4
Date of Sampling	9/23/75	9/24/75	9/25/75	9/26/75
Water Temperature (°C)	16.0	16.0	14.0	15.0
Secchi Disk Depth (cm)	38	25	28	34
Water Velocity (m/sec)	0.62	0.97	0.57	0.61
Total Alkalinity (meq/l)	3.07	2.56	2.61	2.65
Carbon Assimilated ($mg/m^3/hr$) ±95% Confidence Interval	24.20±8.57	5.60±8.57	7.75±8.57	11.23±8.57
Organisms/ml	893	200	267	787
Phytoplankton groups (percent occurrence)				
Diatoms				
A) centric	4.5	6.7	10.0	1.7
B) pennate	58.2	20.0	45.0	49.1
Green Algae				
A) coccoid	13.4	46.7	30.0	8.5
B) filamentous	8.9	20.0	10.0	1.7
Flagellates	7.5	6.7	5.0	33.9
Others	7.5	0.0	0.0	5.1

Table 3. Parameters for Data Set 2.

Description / Station	1	2	3	4
Date of sampling	9/27/75	10/1/75	10/2/75	10/3/75
Water temperature (°C)	15.5	15.0	13.0	13.0
Secchi Disk Depth (cm)	34	27	32	39
Water Velocity (m/sec)	0.61	0.93	0.57	0.64
Total Alkalinity (meq/l)	3.08	2.68	2.72	2.87
Carbon Assimilated ($mg/m^3/hr$) ±95% Confidence Interval	142.28±6.51	8.70±6.51*	8.50±6.51	9.08±6.51
Organisms/ml	12,104	200	626	1440
Phytoplankton groups (percent occurrence)				
Diatoms				
A) centric	63.5	20.0	14.9	0.0
B) pennate	18.0	26.7	29.8	62.0
Green Algae				
A) coccoid	3.3	6.6	12.6	0.0
B) filamentous	0.1	0.0	4.4	3.7
Flagellates	13.9	46.7	38.3	34.3
Others	1.3	0.0	0.0	0.0

*80 minute incubation, correction factor of 3X used.

Table 4. Water quality information measured by Baumann et al. (1975).

Description	Location				
	State Route 46 Bridge 23.3 km above station 1	Red Rock Reservoir at State Route 14 Bridge 14.6 km above station 2			0.4 km Below Red Rock Dam at station 2
		Surface	Mid-depth	Bottom	
Sampling date	9/25/75		9/25/75		9/25/75
Nitrate (mg/l)	0.65	1.06	1.08	1.59	0.94
Phosphorus (mg/l)	2.0	1.4	1.4	1.5	0.7
Organisms/ml	46,500	16,600	23,100	33,000	7,200
Phytoplankton groups (percent occurrence)					
Blue Green	0.1	0.1	0.0	0.0	0.0
Green	9.7	8.4	12.6	9.7	2.8
Flagellates	10.0	13.3	13.4	12.1	28.0
Diatoms	80.0	78.3	74.0	77.0	68.0

DISCUSSION

The amount of carbon assimilated at station 1 was higher than the amount assimilated at all other stations in both data sets. In order to clarify the significance of the differences in the amount of carbon assimilated the randomized block design was applied and F-statistic calculated. For data set 1, F equaled 4.09. From a table of F values it is observed that $F\ [\frac{3}{21}\ .05] = 3.1$. Therefore, variation significant at the .05 level existed in data set 1. For data set 2, F equaled 593.15. From a table of F values it is observed that $F\ [\frac{3}{6}\ .01] = 9.8$. The variation within data set 2 was significant at the .01 level. (Figure 5.)

Information as to the origin of the differences identified by the significant F values could not be determined with the aid of a multiple-range test since there were not enough sampling times.

Noting the positions of the stations, the differences among the productivity values appear to be largely related to the presence of Red Rock Reservoir and its influence on some of the variables which control photosynthesis including temperature, available light, essential nutrients, water velocity and numbers of organisms.

One of the variables (water temperature) is plotted versus station number in Figure 6. Kevern and Ball (1965), while measuring the effect of temperature on photosynthesis

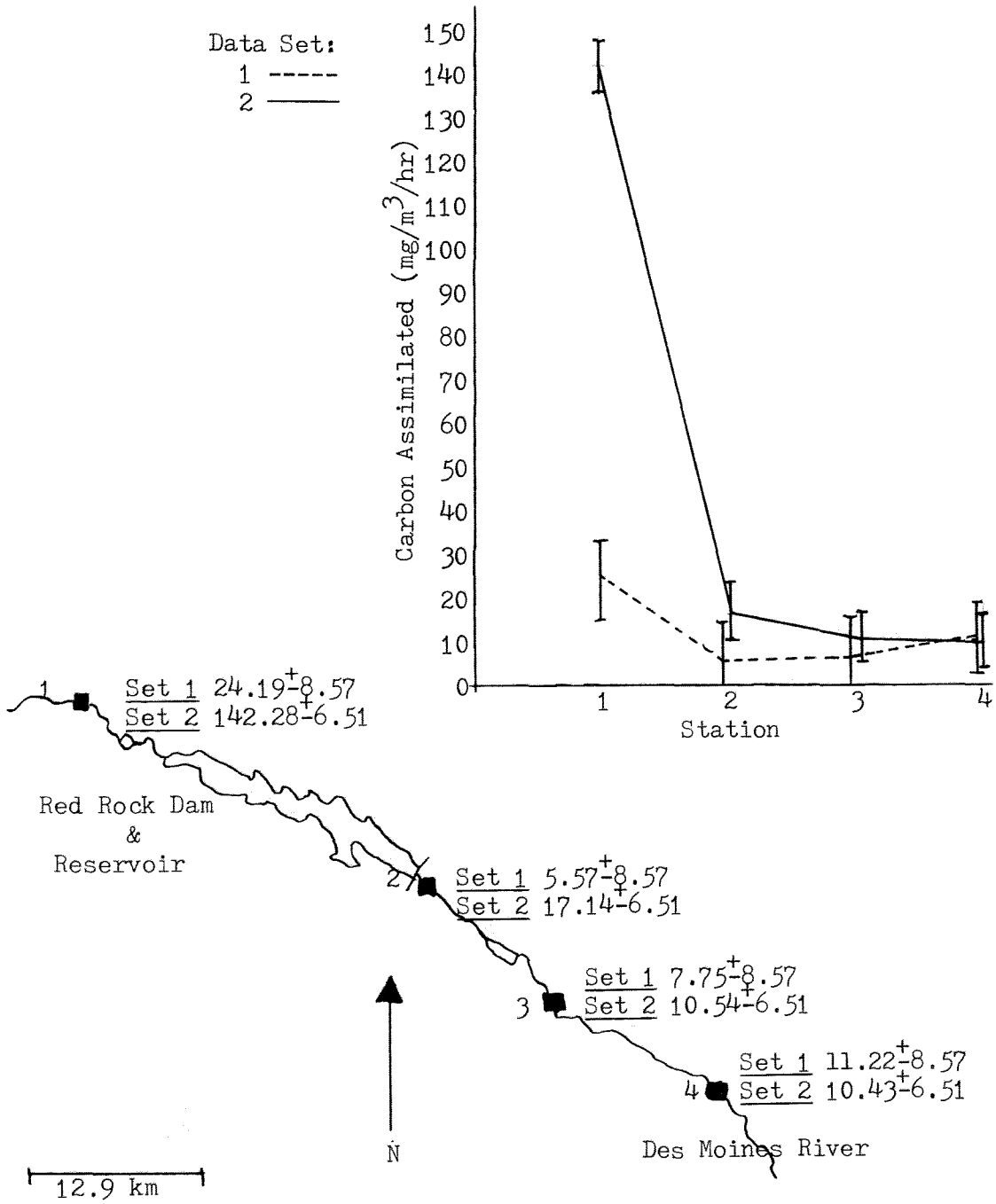


Figure 5. Carbon assimilated versus station number with a 95% confidence interval.

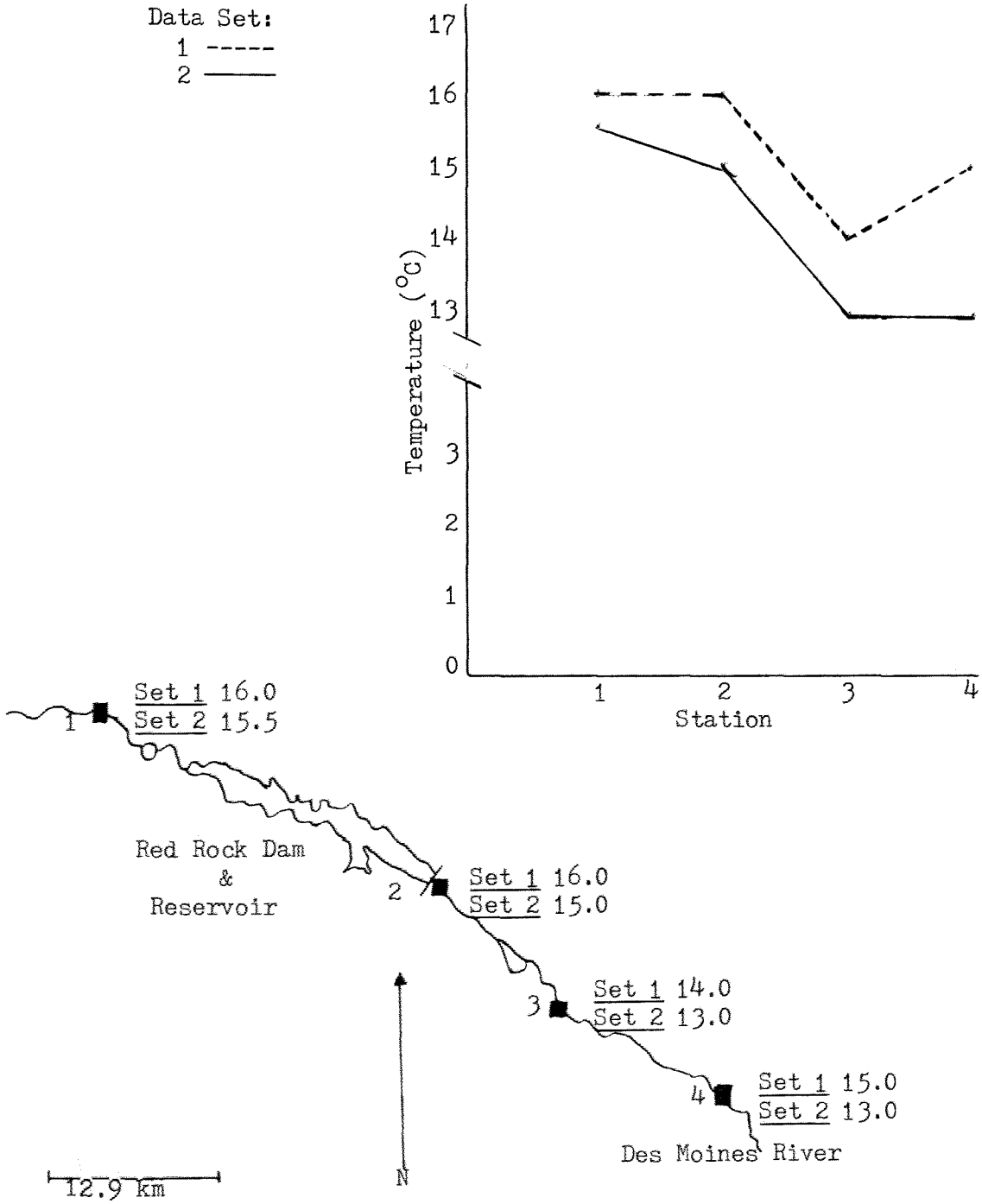


Figure 6. Temperature versus station number.

and respiration, showed that net production was doubled for every 10°C increase. Thus, if the temperature change between stations 1 and 2 was greater than 10°C, consideration of this effect would have to be made. As expected the temperature difference between stations 1 and 2 was not considered large enough to account for differences in production. Nevertheless, the Pearson product-moment correlation (r) (Bruning and Kintz, 1968) was used to see if a statistically valid relationship existed between the temperatures and productivity values recorded. A t-test was then performed to determine the significance of r. In this case $r = 0.20$ and $t = 0.49$ with 6 degrees of freedom. Thus, no significant relationship existed at the .05 level since 2.45 was not exceeded and other factors were considered.

The amount of photosynthesis occurring is also affected by the amount of available light. Differences in the amount of available light between stations could help explain differences in production. Figure 7 shows Secchi disc readings plotted versus station number for both data sets. Light penetration was consistently lower at station 2 (directly below Red Rock Dam) than at the other three sites. However, the positioning of the sample holder in the water had eight BOD bottles completely out of the water at all times regardless of the rotation rate. Even though light availability is a naturally occurring problem, the technique reduced this variable to one of less importance

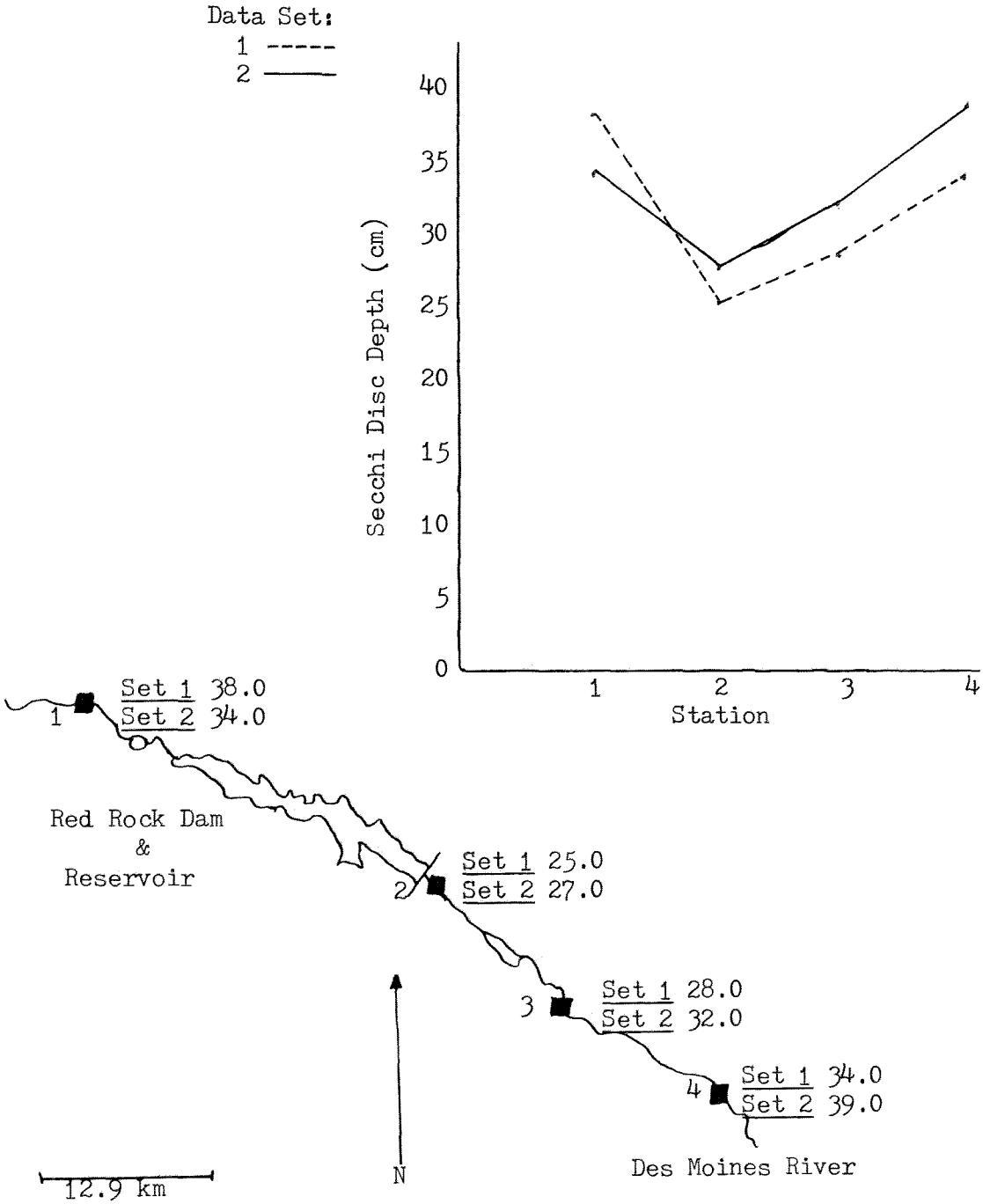


Figure 7. Secchi disc depth versus station number.

reducing the difference in light availability between stations. Statistical testing also verified that Secchi disc reading and productivity values were not significantly related ($r = 0.22$ and $t = 0.55$ with six degrees of freedom).

Nitrogen and phosphorus, usually the nutrients in most limited supply, existed in non-limiting amounts at all stations (Ruttner, 1972). Nitrate levels increased downstream from station 1 (0.65 mg/l to 0.94 mg/l) (Baumann, 1975). Phosphate levels decreased downstream from station 1 (2.0 mg/l to 0.7 mg/l) (Baumann, 1975).

Since Kevern and Ball (1965) indicated a relationship between current velocity and production, current velocity had to be considered as a possible cause for production differences. Figure 8, shows current velocity plotted versus station number for both data sets. The current velocity recorded at station 2 was higher than any of the other stations. If the relationship noted by Kevern and Ball (1965) was operating, production should have been greatest at station 2 due to the maintenance of the steepest diffusion gradients. Production at station 2, however, was the least of the four stations. Statistical analysis showed no significant relationship between current velocity and production ($r = -1.76 \times 10^{-4}$ and $t = -1.0 \times 10^{-3}$ with six degrees of freedom).

The factor which varied the most between stations was the total number of organisms per milliliter of water

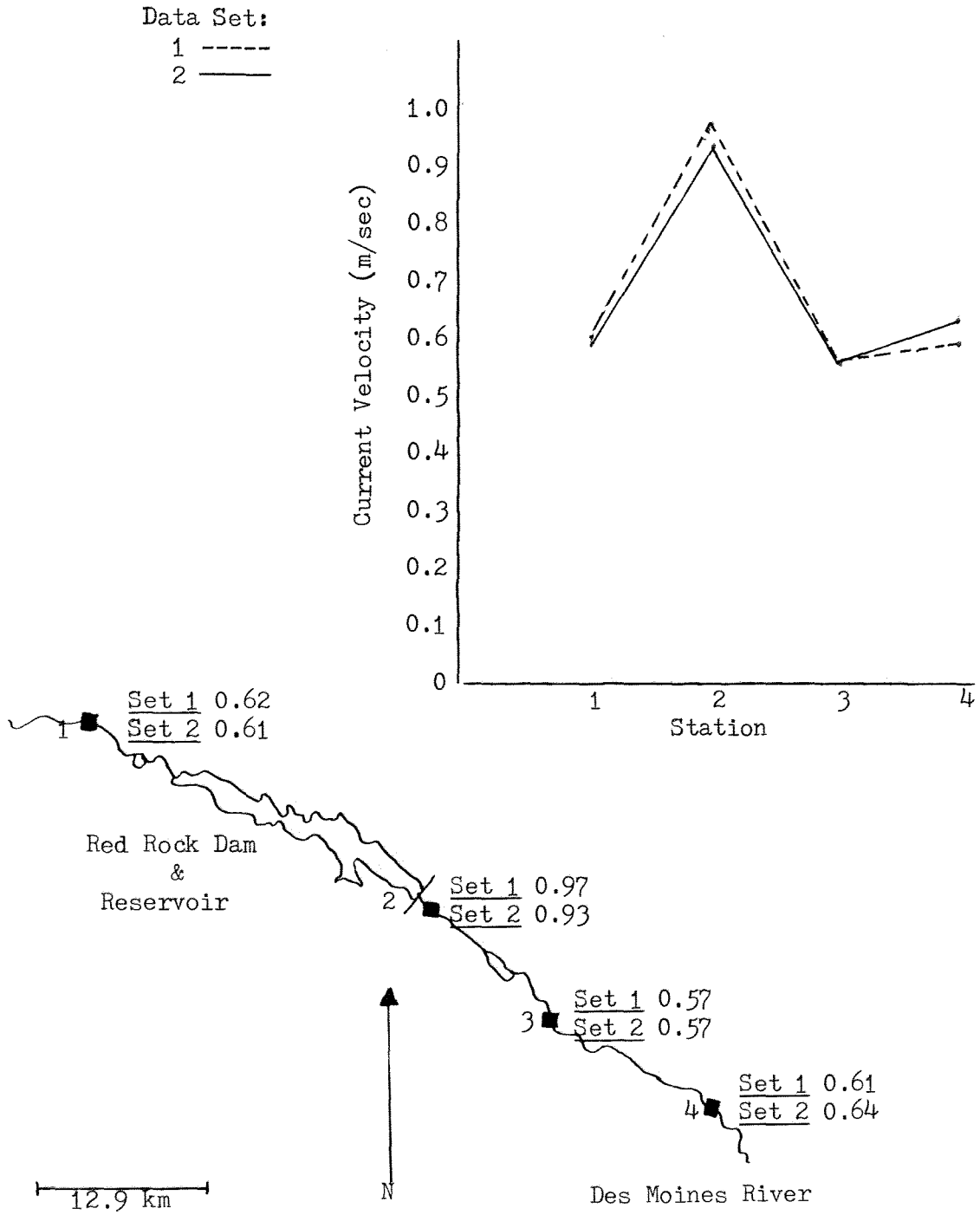


Figure 8. Current velocity versus station number.

sample (Figure 9). Statistical analysis showed a highly significant relationship between the total number of organisms per milliliter and the production values for both data sets ($r = 0.99$ and $t = 17.15$ with six degrees of freedom). The number of organisms per milliliter was lower at station 2 (200 organisms/ml) than at the other stations. This corresponded with the lower production levels at station 2.

There are two possible explanations for this drastic change in phytoplankton numbers. The first explanation for this decrease in plankton as proposed by Chandler (1937) and Rief (1939) deals with the adsorption of phytoplankton onto vegetation, debris or any other objects. If such an effect existed in this situation it should have also occurred within the river above Red Rock Reservoir and affected the numbers of organisms at station 1. Number of organisms per milliliter should have decreased or remained low downstream from station 2 as well. However, numbers were higher at station 1 than at station 2 and the number of organisms per milliliter increased downstream from station 2. In addition, phytoplankton numbers within the reservoir (state highway 14 bridge) increased with depth (Baumann et al., 1975). Baumann et al. measured numbers of phytoplankton per milliliter four times greater above the dam than below the dam (near station 2).

The second possible explanation for the decrease in phytoplankton numbers is the destruction of the cells in

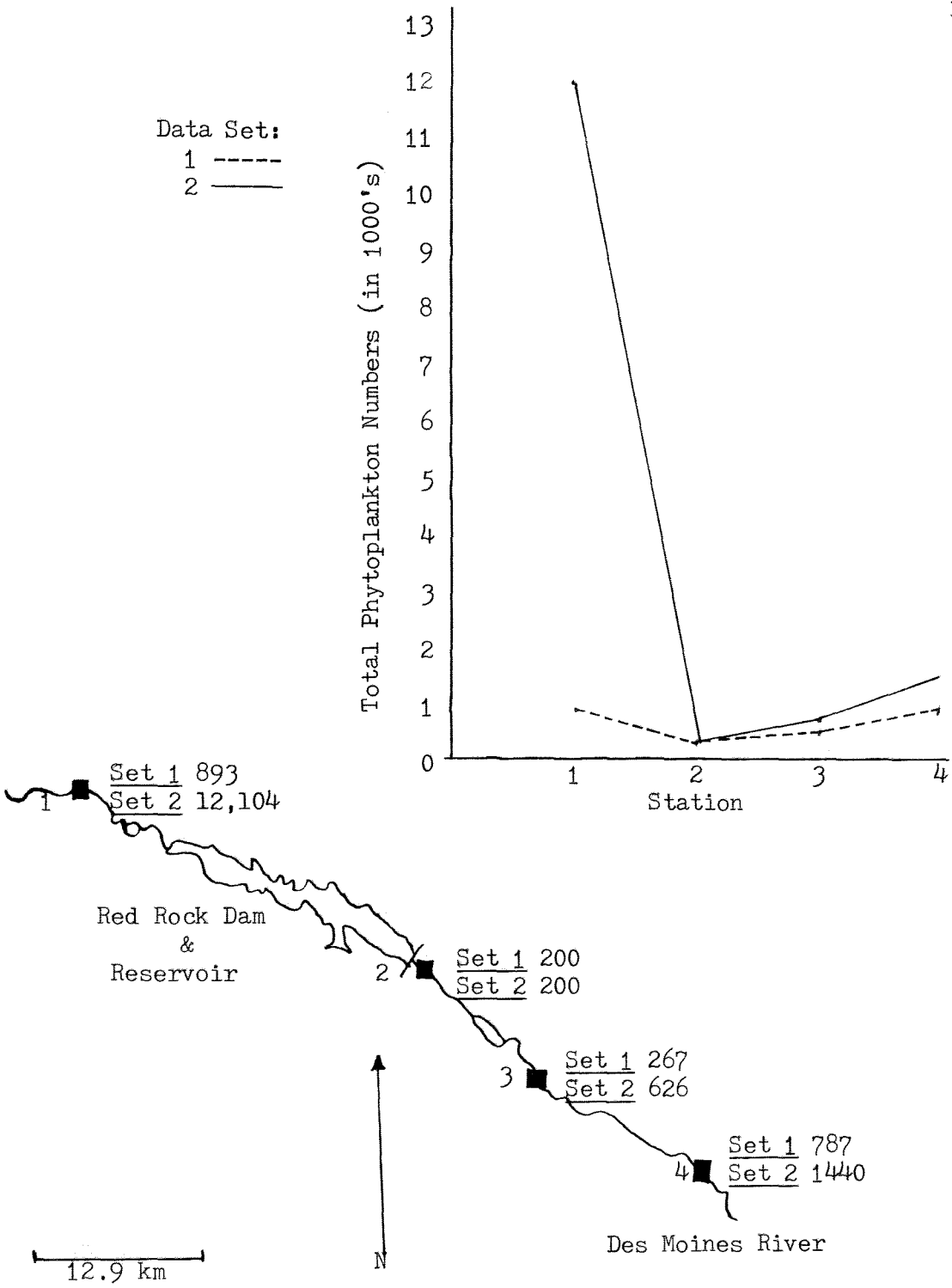


Figure 9. Number of organisms versus station number.

passage through the dam. The fragility of the organisms is best demonstrated by the fact that during filtration through the membrane filter apparatus, the vacuum pressure is not to exceed 0.5 atm to prevent cell rupture (Steemann-Nielsen, 1952). Organisms at the depth necessary to pass through the dam must support a column of water 21.6 meters high (surface of conservation pool to stilling basin depth). The hydrostatic pressure exerted on the organisms at this depth is 2.1 atm greater than the pressure at the surface. This pressure difference is much greater than the pressure difference expressed by Steemann-Nielsen which was sufficient to cause cell rupture of more fragile organisms.

Seemingly in contradiction to the previous statements, the total number of organisms per milliliter of water was greater in the bottom sample of Red Rock Reservoir than at the surface or intermediate depth, as noted earlier (Baumann et al., 1975). Further investigation shows that the average depth of the conservation pool is 3.1 meters. Since the sampling station used by Baumann was at the headwaters of the conservation pool, it can be safely assumed that the bottom sample was taken from a depth of 3.1 meters or less. The hydrostatic pressure at a 3.1 meter depth is 0.3 atm greater than at the surface which is well within Steemann-Nielsen's limit of 0.5 atm. Hydrostatic pressure damage should not have occurred until a depth of 5.2 meters was surpassed. Thus, the total number of organisms per

milliliter should decrease in proportion to an increase in depth beyond 5.2 meters.

In addition, water expelled from the reservoir while the surface level was at 221 meters above mean sea level (the normal level of the conservation pool) moved through the dam with a directional velocity of 10.7 m/sec. It is also possible that the rapid decrease in pressure outside the organisms in passing through the dam is responsible for cell rupture.

It is proposed that the combined effects of increased hydrostatic pressure and rapid pressure changes are responsible for the decrease in phytoplankton numbers measured below Red Rock dam.

SUMMARY AND CONCLUSIONS

The object of this study was to determine the effect of Red Rock Reservoir on the planktonic community within the Des Moines River. This was accomplished by (1) measuring primary productivity of the phytoplankton in terms of C^{14}-uptake using standard lake methods in conjunction with a newly designed sample holding apparatus to overcome most of the problems attributable to current, and (2) ascertaining the fate of phytoplankton passing through Red Rock Reservoir.

Primary productivity at the station above Red Rock Reservoir was higher than at stations below Red Rock Reservoir. The values recorded for water temperature, available

light, essential nutrients and water velocity were shown not to be significantly related to differences in primary production. A significant correlation was found between primary production and the total number of planktonic organisms per milliliter.

Lower population levels below the dam were caused primarily by cell destruction in passage through Red Rock Reservoir.

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APPENDIX

Table 5. Scintillation data for light bottles at station 1 (set 1)

Counts/minute	External Standard Ratio	Counting Efficiency
999.50	6.27	93.3
1019.87	6.21	93.1
1157.98	6.17	93.0
1215.30	6.19	93.0
1223.71	6.11	93.9
1327.58	6.19	93.0
1348.28	6.28	93.3
1405.61	6.28	93.3

Table 6. Scintillation data for dark bottles at station 1 (set 1)

Counts/minute	External Standard Ratio	Counting Efficiency
575.76	6.38	93.5
693.48	6.26	93.3
696.93	6.27	93.3
747.60	6.33	93.4
915.00	6.31	93.3
1020.51	6.24	93.2
1039.52	6.32	93.3
1127.62	6.28	93.3

Table 7. Net disintegrations per minute (dpm) at station 1 (set 1)

Light dpm	Dark dpm	Net dpm
1071.28	615.79	455.49
1095.46	743.28	352.18
1245.14	746.98	498.16
1306.77	800.43	506.34
1317.23	980.71	336.52
1427.51	1094.97	332.54
1445.10	1114.17	330.93
1506.55	1208.60	192.95

Table 8. Calculations using average data at station 1 (set 1)

Total Alkalinity = Normality of the acid x no. of ml of acid x 10

= 0.02 x 15.37 x 10

= 3.07 meq/l

Total C^{12} Available = (Total Alkalinity - Phenolphthalein Alkalinity) x 12

= (3.07 - 0) x 12

= 36.84 mg C^{12}/l

Total Carbon Assimilated = Total C^{12} Available $\times \frac{\text{average } C^{14} \text{ assim.}}{C^{14} \text{ avail.}}$

= 36.84 mg $C^{12}/l \times \frac{388.76 \text{ dpm}}{148{,}000 \text{ dpm}}$

= 0.0968 mg C^{12}/l in 4 hours

= 96.80 mg C^{12}/m^3 in 4 hours

= 24.20 mg $C^{12}/m^3/hr = \bar{x}$

Table 9. Scintillation data for light bottles at station 2 (set 1)

Counts/minute	External Standard Ratio	Counting Efficiency
428.52	6.24	93.2
492.46	6.24	93.2
535.33	6.19	93.0
662.64	6.35	93.5
804.82	6.28	93.3
808.56	6.22	93.1
821.51	6.19	93.0
838.64	6.22	93.1

Table 10. Scintillation data for dark bottles at station 2 (set 1)

Counts/minute	External Standard Ratio	Counting Efficiency
423.81	6.25	93.2
427.92	6.17	93.0
527.47	6.23	93.2
580.10	6.14	93.0
599.16	6.14	93.0
662.38	6.14	93.0
678.56	6.20	93.1
686.41	6.13	92.9

Table 11. Net disintegrations per minute (dpm) at station 2 (set 1)

Light dpm	Dark dpm	Net dpm
459.79	454.73	5.06
528.39	460.13	68.26
575.62	565.95	9.67
708.71	623.76	84.95
862.62	644.26	218.36
868.49	712.24	156.28
883.34	728.85	154.49
900.79	738.87	161.92

Table 12. Calculations using average data at station 2 (set 1)

Total Alkalinity = Normality of the Acid x no. of ml used x 10

= 0.02 x 12.78 x 10

= 2.56 meq/l

Total C^{12} available = (Total Alkalinity - Phenolphthalein Alkalinity) x 12

= (2.56 - 0) x 12

= 2.56 x 12

= 30.72 mg C^{12}/l

Total Carbon Assimilated = Total C^{12} available $\times \frac{\text{average } C^{14} \text{ assim.}}{C^{14} \text{ avail.}}$

= 30.72 mg $C^{12}/l \times \frac{107.37 \text{ dpm}}{148{,}000 \text{ dpm}}$

= 0.0223 mg C^{12}/l in 4 hours

= 22.30 mg C^{12}/m^3 in 4 hours

= 5.60 mg $C^{12}/m^3/hr = \bar{x}$

Table 13. Scintillation data for light bottles at station 3 (set 1)

Counts/minute	External Standard Ratio	Counting Efficiency
539.37	6.22	93.1
560.07	6.15	93.0
561.27	5.61	91.0
579.03	6.14	93.0
667.55	6.05	92.6
765.34	6.25	93.2
828.14	5.97	92.3
1015.01	6.00	92.4

Table 14. Scintillation data for dark bottles at station 3 (set 1)

Counts/minute	External Standard Ratio	Counting Efficiency
415.17	6.03	92.5
449.37	6.05	92.6
548.60	5.98	92.4
570.18	5.98	92.4
583.09	5.90	92.1
590.43	5.96	92.3
618.49	6.03	92.5
645.99	6.00	92.4

Table 15. Net disintegrations per minute (dpm) at station 3 (set 1)

Light dpm	Dark dpm	Net dpm
579.34	449.42	129.92
602.23	485.28	116.95
616.78	593.72	23.06
622.61	617.08	5.53
720.90	633.11	87.79
821.18	639.69	181.49
897.23	668.64	228.59
1098.50	699.12	399.38

Table 16. Calculations using average data at station 3 (set 1)

Total Alkalinity = Normality of the Acid x no. of ml used x 10

= 0.02 x 13.05 x 10

= 2.61 meq/l

Total C^{12} Available = (Total Alkalinity - Phenolphthalein Alkalinity) x 12

= (2.61 - 0) x 12

= 2.61 x 12

= 31.32 mg C^{12}/l

Total Carbon Assimilated = Total C^{12} Available $\times \frac{\text{average } C^{14} \text{ assim.}}{C^{14} \text{ avail.}}$

= 31.32 mg C^{12}/l $\times \frac{146.59 \text{ dpm}}{148{,}000 \text{ dpm}}$

= 0.0310 mg C^{12}/l in hours

= 31.00 mg C^{12}/m^3 in 4 hours

= 7.75 mg $C^{12}/m^3/hr = \bar{x}$

Table 17. Scintillation data for light bottles at station 4 (set 1)

Counts/minute	External Standard Ratio	Counting Efficiency
589.27	6.08	92.8
601.50	6.01	92.4
704.57	6.14	93.0
722.68	6.05	92.6
809.70	5.97	92.3
819.98	6.07	92.7
869.56	6.27	93.3
1120.04	6.15	93.0

Table 18. Scintillation data for dark bottles at station 4 (set 1)

Counts/minute	External Standard Ratio	Counting Efficiency
425.93	6.12	92.9
561.50	6.09	92.8
568.35	5.99	92.4
574.01	6.14	93.0
601.74	6.09	92.8
624.79	6.12	92.9
646.38	6.11	92.9
681.07	5.95	92.3

Table 19. Net disintegrations per minute (dpm) at station 4 (set 1)

Light dpm	Dark dpm	Net dpm
634.99	458.48	176.51
650.97	605.07	45.90
757.60	615.10	142.50
780.43	617.22	163.21
877.25	648.43	228.82
884.55	672.54	212.01
932.00	695.78	236.22
1204.34	737.89	466.45

Table 20. Calculations using average data for station 4 (set 1)

Total Alkalinity = Normality of the acid x n. ml used x 10

= 0.02 x 13.25 x 10

= 2.65 meq/l

Total C^{12} available = (Total Alkalinity - Phenolphthalein Alkalinity) x 12

= (2.65 - 0) x 12

= 31.80 mg C^{12}/l

Total Carbon Assimilated = Total C^{12} Available $\times \frac{\text{average } C^{14} \text{ assim.}}{C^{14} \text{ avail.}}$

= 31.80 mg C^{12}/l $\times \frac{208.95 \text{ dpm}}{148{,}000 \text{ dpm}}$

= 0.0449 mg C^{12}/l in 4 hours

= 44.90 mg C^{12}/m^3 in 4 hours

= 11.23 mg C^{12}/m^3/hr = $\bar{x}$

Table 21. Scintillation data for light bottles at station 1 (set 2)

Counts/minute	External Standard Ratio	Counting Efficiency
2589.66	6.39	93.5
2643.53	6.32	93.3
2950.73	6.24	93.2

Table 22. Scintillation data for dark bottles at station 1 (set 2)

Counts/minute	External Standard Ratio	Counting Efficiency
511.82	6.07	92.7
633.03	6.13	92.9
651.23	6.23	93.2

Table 23. Net disintegrations per minute (dpm) at station 1 (set 2)

Light dpm	Dark dpm	Net dpm
2769.69	552.13	2217.56
2833.37	681.41	2151.96
3166.02	698.75	2467.27

Table 24. Calculations using average data at station 1 (set 2)

Total Alkalinity = Normality of the acid x no. of ml used x 10

= 0.02 x 15.42 x 10

= 3.08 meq/l

Total C^{12} Available = (Total Alkalinity - Phenolphthalein Alkalinity) x 12

= (3.08 - 0) x 12

= 36.96 mg C^{12}/l

Total Carbon Assimilated = Total C^{12} Available $\times \frac{\text{average } C^{12} \text{assim.}}{C^{14} \text{ avail.}}$

= 36.96 mg $C^{12}/l \times \frac{2278.93 \text{ dpm}}{148{,}000 \text{ dpm}}$

= 0.5691 mg C^{12}/l in 4 hours

= 569.10 mg C^{12}/m^3 in 4 hours

= 142.28 mg $C^{12}/m^3/hr = \bar{x}$

Table 25. Scintillation data for light bottles at station 2 (set 2)

Counts/minute	External Standard Ratio	Counting Efficiency
485.06	6.26	93.3
515.13	6.16	93.0
591.19	6.07	92.7
596.48	5.94	92.2

Table 26. Scintillation data for dark bottles at station 2 (set 2)

Counts/minute	External Standard Ratio	Counting Efficiency
400.64	6.06	92.7
404.16	6.09	92.8
491.25	6.19	93.0
696.54	6.15	93.0

Table 27. Net disintegrations per minute (dpm) at station 2 (set 2)

Light dpm	Dark dpm	Net dpm
519.90	432.19	87.71
553.90	435.52	118.38
637.75	528.23	109.52
646.94	748.97	-102.03

Table 28. Calculations using average data at station 2 (set 2)

Total Alkalinity = Normality of the acid x no. of ml used x 10

= 0.02 x 13.4 x 10

= 2.68 meq/l

Total C^{12} Available = (Total Alkalinity - Phenolphthalein Alkalinity) x 12

= (2.68 - 0) x 12

= 32.16 mg C^{12}/l

Total Carbon Assimilated = Total C^{12} Available $\times \frac{\text{average } C^{14} \text{ assim.}}{C^{14} \text{ avail.}}$

= 32.16 mg $C^{12}/l \times \frac{53.40 \text{ dpm}}{148{,}000 \text{ dpm}}$

= 0.0116 mg C^{12}/l in 1.33 hours

= 11.60 mg C^{12}/m^3 in 1.33 hours

= 8.70 mg $C^{12}/m^3/hr = \bar{x}$

Table 29. Scintillation data for light bottles at station 3 (set 2)

Counts/minute	External Standard Ratio	Counting Efficiency
637.92	6.39	93.5
770.36	6.31	93.3
780.18	6.11	92.9
943.16	6.15	93.0

Table 30. Scintillation data for dark bottles at station 3 (set 2)

Counts/minute	External Standard Ratio	Counting Efficiency
602.22	6.24	93.2
639.39	6.27	93.3
651.10	6.25	93.2
666.62	6.23	93.2

Table 31. Net disintegrations per minute (dpm) at station 3 (set 2)

Light dpm	Dark dpm	Net dpm
682.27	646.16	36.11
825.68	685.31	140.37
839.81	698.61	141.20
1014.15	715.26	298.89

Table 32. Calculations using average data at station 3 (set 2)

Total Alkalinity = Normality of the acid x no. ml used x 10

= 0.02 x 13.6 x 10

= 2.72 meq/l

Total C^{12} Available = (Total Alkalinity - Phenolphthalein Alkalinity) x 12

= (2.72 - 0) x 12

= 32.64 mg C^{12}/l

Total Carbon Assimilated = Total C^{12} Available $\times \frac{\text{average } C^{14} \text{ assim.}}{C^{14} \text{ avail.}}$

= 32.64 mg $C^{12}/l \times \frac{154.14 \text{ dpm}}{148{,}000 \text{ dpm}}$

= 0.0340 mg C^{12}/l in 4 hours

= 34.00 mg C^{12}/m^3 in 4 hours

= 8.50 mg $C^{12}/m^3/hr = \bar{x}$

Table 33. Scintillation data for light bottles at station 4 (set 2)

Counts/minute	External Standard Ratio	Counting Efficiency
651.89	6.32	93.3
706.77	6.19	93.0
825.07	6.07	92.7
874.65	6.25	93.2

Table 34. Scintillation data for dark bottles at station 4 (set 2)

Counts/minute	External Standard Ratio	Counting Efficiency
570.94	6.24	93.2
599.70	6.05	92.6
651.00	6.19	93.0
653.23	6.13	92.9

Table 35. Net disintegrations per minute (dpm) at station 4 (set 2)

Light dpm	Dark dpm	Net dpm
698.70	612.60	86.10
759.97	647.62	112.35
890.04	700.00	190.04
938.47	703.15	235.32

Table 36. Calculations using average data at station 4 (set 2)

Total Alkalinity = Normality of the acid x no. of ml used x 10

= 0.02 x 14.35 x 10

= 2.87 meq/l

Total C^{12} Available = (Total Alkalinity - Phenolphthalein Alkalinity) x 12

= (2.87 - 0) x 12

= 34.44 mg C^{12}/l

Total Carbon Assimilated = Total C^{12} Available $\times \frac{\text{average } C^{14} \text{ assim.}}{C^{14} \text{ avail.}}$

= 34.44 mg $C^{12}/l \times \frac{155.95 \text{ dpm}}{148{,}000 \text{ dpm}}$

= 0.0363 mg C^{12}/l in 4 hours

= 36.30 mg C^{12}/m^3 in 4 hours

= 9.08 mg $C^{12}/m^3/hr = \bar{x}$